Quantitative morphology and color gradients of E+A galaxies in distant galaxy clusters

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Three basic scenarios have been invocated to explain the sudden rise and decline of star formation in distant clusters that lead to the transformation of "active" galaxies into the elliptical− and S0−types which today dominate rich clusters, i.e. the so called Butcher-Oemler effect, (Butcher & Oemler,1978). These are: galaxy interactions or mergers with nearly equal mass neighbors (Lavery & Henry, 1988), gas-rich field galaxies running for the first time into the hot intercluster gas which ignites a brief but energetic episode of star formation (Bothun & Dressler, 1986), and high speed close encounters of gas-rich galaxies resulting in non-disruptive interactions or "galaxy harassment", (Moore, 1996).

Although neither of the proposed mechanisms for triggering star formation has a definitive answer in its favour, the high resolution of the HST images of distant clusters has recently provided a unique tool to face this question. Indeed, it allows us to study the spatial distribution of the starburst and thus to distinguish among the physical mechanisms at its origin. In the case of an infalling or harassed spiral the enhanced star formation would likely be a galaxy-wide phenomenon, or confined to the disk. If, on the other hand, the original galaxy was an elliptical that accreted gas from a dwarf galaxy, the burst signatures should be detectable as a bluer color of the nuclear region. Finally, in interacting or merging disk galaxies both behaviours have been observed: galaxies with starburst concentrated to the very center (Scoville et al.,1991) and others that show enhanced star formation on a galaxy-wide scale (Standford, 1991).

We focuse on one class of "active" galaxies, the post-starburst or E+A galaxies, the latter being *only* a description of the spectra which appear to have an A-star component added to an old elliptical like component. These spectral features are interpreted as evidence of a recent ($<$ 1.5 Gyr) burst of star formation. Ground based narrow-band photometry of 4 intermediate redshift clusters at z=0.4-0.5 has provided us with a sample of 73 E+A galaxies being secure cluster members (Belloni et al.,1995; Belloni & Röser, 1996). This is the largest sample of such galaxies found to date in distant clusters. Cluster membership and spectral type have been obtained by fitting the observed low-resolution spectral energy distributions with template spectra built up with Bruzual & Charlot (1997) population synthesis models. They represent the temporal evolution of a strong star formation episode (involving 20% of the original galactic mass) in an elliptical galaxy or in a spiral galaxy with star formation truncated after the burst. Our approach allows us to detect bursts younger than 2 Gyr while galaxies with an older burst will not be distinguished from a passively evolving elliptical galaxy.

Due to the small HST field of view only for 33 E+A galaxies HST images are available (WFPC2). We have retrieved them and determined: a) **surface brightness profiles** for all E+A galaxies but those showing highly irregular morphology. A fit with an exponential or a $r^{-1/4}$ law has been performed and for disk galaxies a Hubble type classification has been attempted on the basis of the buldge to disk ratio, b) **color gradients** for the 10 E+A galaxies in Cl0016+16 (observed in the F555W and F814W filters).

Table 1. Results of the surface brightness analysis of 33 E+A galaxies in intermediate redshift clusters. The E+A fraction is given with respect to the secure cluster members, about 120 galaxies brighter than m_R=22.5 per cluster. For merging/interacting galaxies we indicate if possible whether they appear disk or bulge dominated.

Cluster	E+A	E+A (HST)	Morph. Elliptical	Morph. S0-Sa	Morph. Sb-Sc	Merger Interact.
Cl0016+16 (z=0.54)	20 (21%)	11	1	3	6	1 Disk-dominated
Cl0939+47 (z=0.41)	35 (22%)	11			7	4
Cl0303+17 (z=0.41)	22 (22%)	7		1	5	1 Irregular
Cl1447+26 (z=0.38)	8 (9%)	4		1	1	2 Disk-dominated

We found that **most of the galaxies and all those showing signs of interaction are disk systems** judging from the exponential nature of the profiles (Tab.1). In our sample only one E+A galaxy has a regular elliptical profile. We also found that the E+A galaxies in Cl0016+16 show little spatial variation in V-I colors (restframe U-V) (Fig.1). Only one young E+A galaxy with estimated post-starburst age 0.8 Gyr has a starburst predominantly located in the nucleus whereas a second one has a weaker evidence of the same behaviour. However, the E+A color gradients are flatter compared to those of cluster ellipticals (Belloni et al, 1997) that are consistent with the Δ(U-R)/Δlog r=−0.23 mag observed in the nearby ones (Franx et al.,1993). Thus, our large and homogeneous sample of distant E+A galaxies confirms the claim that their **enhanced star formation is a galaxy-wide phenomenon.** Indeed, similar results have been obtained for the post-starburst galaxies in the Coma cluster by Caldwell et al. (1996). We speculate that strong interactions did not create most of the post-starburst galaxies in our representative sample of galaxy clusters at z=0.4−0.5. Non-disruptive interactions among galaxies or interactions between galaxies in

the cluster or subcluster structures and the ICM are likely to be the dominant mechanism.

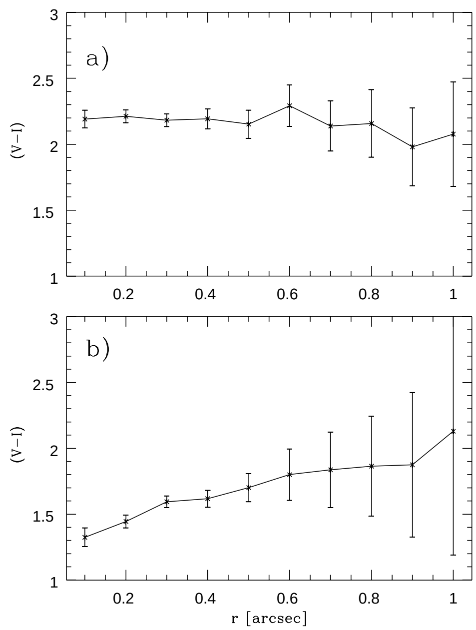

Fig. 1. a) Typical color gradients of E+A galaxies in CL0016+16 (z=0.54). b) One of the two E+A galaxies in Cl0016+16 showing strong color gradients. The very blue central colors (typical of spirals) indicate that the starburst is located in the nucleus. $1''$= 7.3 Kpc (H_o=50 km sec^{-1} Mpc^{-1} and q_0=0)

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